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EBIS CHARGE BREEDER AT ANL AND ITS INTEGRATION INTO ATLAS

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Abstract

An Electron Beam Ion source Charge Breeder (EBIS-CB) has been developed to charge breed CARIBU radioactive beams at ATLAS and it is now in the final stages of off-line commissioning. Within the next year, the EBIS-CB will replace the existing ECR charge breeder to increase the intensity and improve the purity of reaccelerated radioactive ion beams. The integration of the new EBIS-CB requires:

a. Building a new electrostatic low energy beam transport line (LEBT) from CARIBU to the EBIS-CB that will ensure successful seeding into the trap.
b. Modifications to the existing ATLAS LEBT to accommodate the injection of the charge bred ions into the post accelerator.

In this paper we will describe the beam line design and present beam dynamics simulation results.

INTRODUCTION

The CAlifornium Rare Isotope Breeder Upgrade (CARIBU) facility is capable of generating a wide variety of rare isotope beams (RIB) of heavy ions in the 80-160 mass range from the fission fragments of a ^{252}Cf source [1]. After thermalization in a helium gas catcher the ions are mass-separated using a magnetic spectrometer, charge bred in an electron-cyclotron resonance (ECR) ion source, and then injected into the Argonne Tandem Linear Accelerator System (ATLAS) for post acceleration. Plasma-surface interactions in the ECR chamber results in significant contamination of the extracted beams, which subsequently obscures the signature of low intensity RIBs. To address this, a charge breeder based on the electron beam ion source (EBIS) concept has been developed at ANL for the CARIBU system [2]. Higher breeding efficiency and most importantly, much better purity of radioactive ion beams are expected with the EBIS charge breeder. The CARIBU EBIS-CB utilizes technology recently developed at Brookhaven National Laboratory (BNL) [3].

The offline commissioning of the EBIS-CB is now approaching its final stages and 20% breeding efficiency into ^{133}Cs^{27} within 23 ms has already been demonstrated [4]. The integration into ATLAS is scheduled to commence later this year. This paper will focus on beam dynamics studies for the beam transport line from CARIBU to the EBIS-CB and from the EBIS-CB to ATLAS.

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BEAM TRANSPORT FROM THE EBIS-CB TO ATLAS

The beam transport line from the EBIS-CB to the ATLAS RFQ is shown in Figure 2. In this section of the beam line it is necessary to separate the desired radioactive beams from the residual gas contaminants. The residual gas spectrum was measured during the EBIS offline commissioning and is depicted in Figure 1. Radioactive beams delivered from CARIBU will be charge-bred to a charge-to-mass ratio in the range $1/6 \leq Q/A \leq 1/4$ in every 10-30 ms breeding cycle. This corresponds to a dipole current between 36 A and 45 A in the figure. The intensity of the O^3 peak which lies in that range is estimated at ~10^5 ions per pulse. This should be compared to the intensity of radioactive beams delivered by CARIBU which will be in the order of 10^3-10^4 ions per pulse.

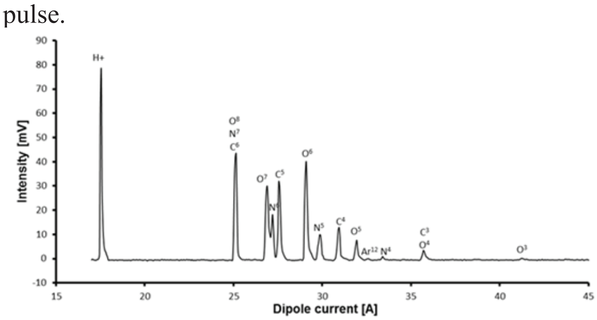

Figure 1: Residual gas spectrum after 30ms breeding.

It has already been noted by several authors that electron beam ion sources tend to generate beams with significant energy spreads [5]. This is due to heating of the ions in the trap by the electron beam [6], ionization heating [7], and heating by plasma instabilities [8] or as a result of the extraction process [9]. In order to handle the significant energy spread Nier-type spectrometers are usually employed, so the beam width at the mass selection slit does not depend on the energy spread at the first order [10]. However, in our case it was decided not to employ a Nier-type spectrometer due to the cost of replacing one of the existing dipole magnets with an electrostatic deflector capable of handling beams with relatively high electric rigidities (up to ~200 kV). Furthermore, the residual magnetic dispersion would prohibit the possible upgrade to a multi user facility, where beams with different magnetic rigidities will be transported simultaneously [11]. Instead, it was decided to use the existing dipoles and make the 180° bend doubly achromatic with the mass selection performed between the 90° dipoles. In addition, it was required that after the 180° bend the beam will be symmetric and focused into the small aperture of the Multi Harmonic Buncher (MHB)

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[12] in order to avoid ion loss. These requirements can be achieved simultaneously by introducing a set of two electrostatic doublets placed symmetrically between the dipoles, as shown in Figure 2.

In order to evaluate the beam line design a particle distribution was generated and traced using the beam dynamics code TRACK [13] from the EBIS-CB platform through the low energy beam transport line, and then injected into the ATLAS RFQ. The following estimate was used for the emittance of the charge bred beams extracted from the EBIS-CB [14]:

$$\varepsilon = 2r_{ion}\sqrt{\frac{\Delta U}{U_{acc}} + \frac{r_{ion}^2 qB^2}{2mU_{acc}}} \qquad (1)$$

Where ΔU is the radial potential well depth at the electron beam boundary, B is the magnetic field in the trap, U_{acc} is the accelerating voltage and q and m are the ions charge and mass respectively. In equation (1) r_{ion} is the radius of the ion beam at extraction and in order to get an upper bound for the emittance we used $r_{ion}=r_e$, the radius of the electron beam in the trap. This yields $\varepsilon_{n,full}=0.2\ \pi$ mm mrad, so twice that value was used for the beam transport simulations shown here ($\varepsilon_{n,full}=0.45\ \pi$ mm mrad). A value of 115 eV/Q was used for the energy spread at extraction, based on a survey of the available literature [15,16,17]. Figure 3 shows the envelopes (RMS and full, horizontal in blue and vertical in red) during the beam propagation. No particle loss was observed in the simulations. Based on the analysis by Wiedemann [18], for a given beam emittance the mass resolving power is proportional to the beta function in the middle of the dipole. Therefore the beam size in the dipole is large in order to maximize the resolving power.

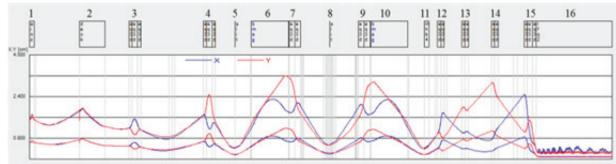

Figure 3: Beam envelopes during the transport from the EBIS-CB platform to the ATLAS RFQ. 1 - einzel lens; 2 - acceleration to 30.6keV/u; 3,4,15 - electrostatic triplets; 5,8 - slits ; 6,10 - 90° dipoles; 7,9,12-14 - electrostatic doublets; 10 - MHB; 16-ATLAS RFQ.

TRACK was also used to evaluate the mass resolving power of the spectrometer. Three charge state distributions were tracked to the mass selection slit. All the particles in one distribution had the mass m_0 while particles in the other distributions had masses $m_0(1\pm\delta_m)$. For this simulation $\varepsilon_{n,full}=0.2\ \pi$ mm mrad was used with the same RMS energy spread as before. Figure 4 shows the projection of the beams at the mass selection slit with $\delta_m=6.7\cdot10^{-3}$. Based on the above discussion suppression of the contaminations by two orders of magnitude may be required. Hence the mass resolving power is defined by resolving 99% of the particles. Based on this analysis the mass resolving power under these conditions is $R_m\sim150$.

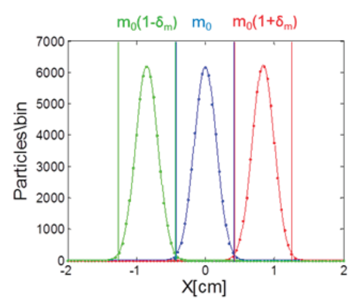

Figure 4: Beam profiles at the mass selection slit, $\delta_m=6.7\cdot10^{-3}$. Vertical lines indicate intervals containing 99% of the particles in each distribution.

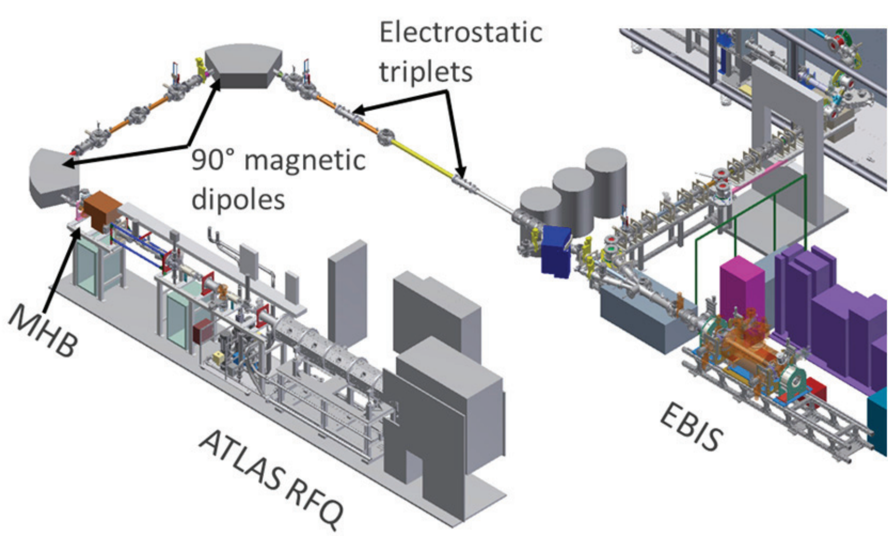

Figure 2: A 3d model of the low energy beam transport line from the EBIS-CB platform to the ATLAS RFQ.

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BEAM TRANSPORT FROM CARIBU TO EBIS

A preliminary design for the beam transport line from CARIBU to the EBIS-CB was described in [19]. However the incorporation of a Multi Reflection Time of Flight (MR-TOF) mass spectrometer [20] on the CARIBU platform necessitated major revisions. Furthermore, simulations show that the beam emittance may increase significantly during the multiple reflections in the MR-TOF [21]. On the basis of these simulations we estimate the beam emittance upon extraction from the MR-TOF at $\varepsilon_{n,full}=1\cdot10^{-2}$ π mm mrad, so $\varepsilon_{n,full}=2\cdot10^{-2}$ π mm mrad was used in the beam transport simulations shown here. This is comparable to the nominal acceptance of the EBIS-CB $A_{n,full}=2.5\cdot10^{-2}$ π mm mrad [22], so beam distortions must be minimal.

A 3d model of the beam transport line is shown in Figure 5. After extraction from the MR-TOF the beam will be deflected by 180° vertically using four electrostatic spherical benders (EB1-4). As described in [23] the transformation generated by the four benders is achromatic and all the second order geometrical aberrations are cancelled. The beam is then accelerated to 36 keV in two steps using a pulsed accelerator (PA). Seven electrostatic doublets (ED1-7) and six additional spherical electrostatic benders (EB5-8, EB11-12) guide the beam towards the EBIS-CB injection-extraction line. The beam envelopes during the beam propagation from the MR-TOF exit to the EBIS-CB are shown in Figure 6 (top). No beam loss is observed during the transport. Also shown in Figure 6 (bottom), are the phase space projections of the beam on the two transverse planes when it reaches the EBIS-CB. The beam is matched to the EBIS-CB acceptance and the distortions are minimal.

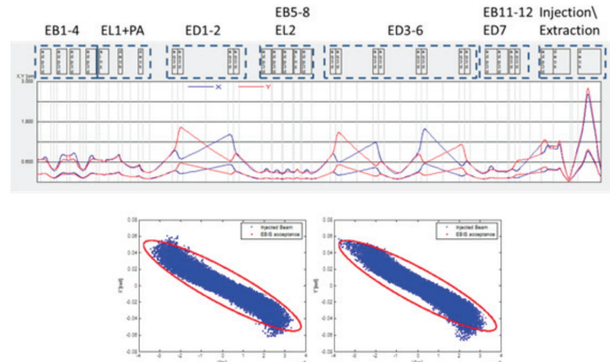

Figure 6: Top: beam envelopes during the beam transport from the MR-TOF exit to the EBIS-CB. Bottom: phase space projections of the beam at injection to EBIS-CB.

SUMMARY

The beam transport lines from the CARIBU to the EBIS-CB and from the EBIS-CB to the ATLAS RFQ were presented in this paper. A mass spectrometer based on the existing two dipoles in the ATLAS LEBT will achromatically resolve the radioactive beams from residual contaminations with a mass resolution of ~150. It should be noted that preliminary estimates of the emittance and energy spreads produced by the EBIS-CB indicate that they are significantly lower than the values used in the simulations so the achieved resolving power may be higher. In addition, the ATLAS RFQ will provide additional suppression of contaminants. Simulations of the beam transport in both beam lines indicate no losses and minimal emittance growth. The construction of the beam lines and integration of the EBIS-CB into ATLAS is scheduled to commence later this year.

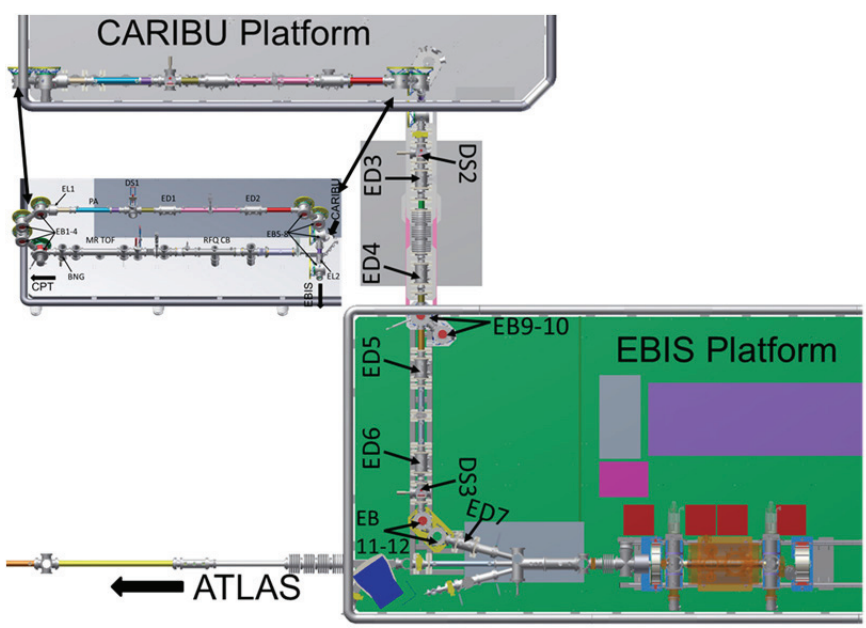

Figure 5: A 3d model of the transport line from CARIBU to the EBIS-CB: EB1-12 – spherical electrostatic benders; ED1-7 – electrostatic doublets; EL1-2 einzel lenses; PA – pulsed accelerator; MR-TOF – Multi Reflection Time of Flight spectrometer;

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